other existing radio services (e.g., point-to-point microwave) with virtually no threat of causing or suffering harmful interference. Specifically, integrating SDMA with PCS will:

- Significantly increase the effective channel capacity of PCS base stations;
- Significantly increase the quality of communications links;
- Significantly reduce the required amount of transmitted power from both base stations and mobile units;
- Lower the overall system cost by reducing the number of base stations required to handle a given system load;
- Significantly increase flexibility in system architecture;
- Significantly reduce or completely eliminate harmful interference to and from existing primary services resulting from co-primary PCS system operations; and
- Facilitate extremely precise position determination capabilities in a PCS system with no significant increase in deployment cost.

* * * * *

SDMA technology is fully compatible with all analog and digital signal modulation schemes proposed for PCS systems, including FDMA, TDMA, and CDMA. Spectral efficiency and signal-to-noise ratio ("SNR") gains that can be realized with SDMA technology vary with respect to the underlying modulation scheme and the number of antennas in an SDMA antenna array at a cell. SDMA testing to date indicates that spectral capacity increases of a factor as high as 10 relative to omni-directional PCS platforms are technically and economically feasible. The increased spectral capacity and signal quality that SDMA provides can be traded off in PCS system design for reductions in the number of base stations, to enhance signal strength, or for increases mobile unit talk time. A detailed technical description of individual SDMA system components and possible SDMA PCS network configurations is provided in Section 3 of Appendix A.

As discussed more fully in the following Section, SCI plans to conduct an aggressive program of PCS SDMA field trials over the next several months. SCI anticipates the initiation of full-scale commercial production of PCS SDMA equipment within two years.

III. DESCRIPTION OF THE SCI PCS RESEARCH AND DEVELOPMENT PROGRAM

A. General PCS Research And Development Activities

OWT has been researching the viability of PCS in the United States since 1990. Upon grant of an FCC experimental authorization in December 1991, OWT proceeded with its plans to engage in an aggressive program of PCS research, including field tests and demonstrations in Seattle, Washington, and in Los Angeles and Long Beach, California.[3] OWT's experimental plan calls for evaluating possible deployment scenarios for CT-2, CT-2 Plus, and CT-3 PCS platforms operating in the range of 901-960 MHz and in the range 1800-2200 MHz frequency bands. OWT is addressing pivotal PCS

[3] File No. 2029-EX-PL-91; Call Sign KK2XAL.

issues such as techniques for interservice sharing, user location management and traffic engineering. Additionally, OWT is studying overall PCS administration, and developing proprietary systems for customer billing, operator and maintenance services, intersystem administration, and system monitoring. OWT is licensed to conduct field experiments in Seattle, Washington, and in Los Angeles and Long Beach, California. Concurrent with the submission of the instant Request For Pioneer's Preference, OWT is filing an application to assign its PCS experimental license to SCI. Timely Commission approval of the assignment application will serve the public interest by precluding unnecessary delays in SCI's initiation of PCS SDMA field trials that could result if SCI were to apply at this time for an entirely new experimental authorization. SCI will be able to take advantage of important third party relationships, formed by OWT to facilitate field experimentation in three key PCS operating environments defined as a result of market research performed by OWT (i.e., residential, public access, and commercial/business).

B. SCI's Plan For PCS SDMA Implementation

SCI is in the process of executing a two-year plan for commercial roll-out of PCS SDMA technology, beginning with preliminary field tests to be conducted within the next few months, pursuant to Commission approval of OWT's application to assign its existing experimental license to SCI. SCI's plan culminates in mass production and installation of SDMA base stations in fully operational PCS systems by early 1994.

Through July of 1992, SCI will perform additional SDMA testing in a controlled RF environment (anechoic chamber), and in SCI's robust computer simulator. These tests are being conducted to reaffirm and expand data obtained in previous analyses on the performance envelope of the SDMA receive system and its sensitivity to hardware imperfections under controlled conditions. During this period, testing will be expanded to include field tests of a full-duplex transmit/receive SDMA system.

Also during the first four months, propagation studies in the 901-960 MHz and 1850 to 1990 MHz bands will be performed to ascertain relevant RF properties of the environments in which PCS SDMA systems will be operating. CT-2 platforms will be deployed at Stevedoring Services of America, located at Pier 18, Seattle, Washington, and at the Sheraton Seattle Hotel & Towers, and technical and market surveys will be undertaken.

A robust full-scale prototype PCS SDMA system will be designed, constructed, and tested between August 1992 and April 1993. The SDMA system will be integrated into a CT-2 Plus base station and once tested, three such base stations will be constructed, tested, and integrated into a small prototype PCS SDMA network.

Deployment of the CT-2 platforms at Stevedoring Services of America and the Sheraton Seattle Hotel & Towers will be expanded from September 1992 to January 1993. A CT-2 platform will be deployed at View Ridge Elementary, School (Seattle Public Schools) and in the adjacent residential neighborhood. Also, a CT-3 (TDMA) platform will be deployed at the Sheraton Seattle Hotel & Towers during this period. Technical and market surveys will be conducted for each platform.

SCI plans to begin CT-2 Plus platform deployment in February 1993 at the above-mentioned Seattle sites. SCI plans to include test and demonstration sites in Los Angeles, Long Beach and San Francisco. Once again, technical and market surveys will be conducted.

Full-scale testing of SCI's PCS SDMA system will begin in May 1993 with 200-users on a CT-2 Plus platform. System performance will be analyzed and problems solved as they are encountered. These tests will determine the system requirements for the final prototype design modifications prior to mass production and system installation. This phase of testing should be complete by September 1993.

Design release for production of PCS SDMA systems is expected by December 1993. The first PCS SDMA production units are expected to be available in the first quarter of 1994, and will be installed and brought on-line soon thereafter.

IV. IMPLEMENTING SDMA IN THE PCS ENVIRONMENT IS TECHNICALLY AND ECONOMICALLY FEASIBLE

A. Extensive Testing Conducted To Date Conclusively Demonstrates The Technical Feasibility of Implementing PCS SDMA

As fully demonstrated in Appendix A, and in Section III *supra*., SDMA PCS technology is at a level of development from which commercial implementation in the next two years is clearly feasible. A rigorous series of computer simulations and actual SDMA prototype system tests confirming the precise accuracy and flexible operation of SCI's SDMA technology, documented in Appendix A hereto, conclusively demonstrate the feasibility of PCS SDMA technology. Specifically, the ability of SCI's SDMA technology to spatially demultiplex co-channel signals on a dynamic real-time basis, and provide SNR at the output of the SDMA processor sufficient for accurate demodulation has been successfully demonstrated. In addition, the ability of SCI's SDMA technology to directionally transmit multiple co-channel signals to multiple receivers in a cell service area, with sufficient SNR at each receiver to permit successful demodulation of the intended signal is demonstrated in Section 5.1 and Figure 5.4 of Appendix A. Based on the foregoing, SCI submits that it has demonstrated the technical feasibility of its PCS SDMA technology, as required by Section 1.402(a) of the Commission's Rules.

B. PCS SDMA Implementation Is Economically Feasible and Will Yield Substantial Increases In PCS Profitability

Implementation of PCS SDMA is economically feasible, will yield substantial cost savings in system deployment costs, and increase the profitability of PCS systems. Section 6 of Appendix A, prepared by SCI's Chief Scientist and his staff, provides various cost factors relating to the implementation of PCS SDMA. The business planning staff of SCI has developed a proprietary model that augments the discussion of SDMA economics in Section 6 of Appendix A.

SCI's model uses the demographics of the central business district of Los Angeles, California PCS market ("LACBD") and quantifies the cost savings expected from reductions in the number of PCS base stations that will result from use of SDMA. SCI's model takes account of the SDMA implementation cost data provided in Appendix A, and incorporates SCI's estimates of PCS subscriber density and calling patterns. SCI uses grades of service and busy loading parameters typical in a wireline telephone system. SCI's selection of wireline telephone loading and service quality characteristics reflects SCI's belief that PCS will be required to meet wireline service quality and capacity in many market sectors. The model conservatively establishes a Grade of Service of .01, and a busy hour of 200 seconds per subscriber. SCI's assumptions associated with the model are as follows:

SCI Model Assumptions

•	Busy Hour Seconds Per Subscriber:	200
•	Grade of Service	.01
•	Population Density/People per sq. mi.	13,948
•	City Size	484.97 sq. mi.
•	Coverage Area	100%
•	Penetration*	5%
•	Amount of Spectrum	25 MHz
•	KHz per channel	100 KHz
•	No of channels Per Base	6
•	SDMA Multiplier	6
•	Antennas Per Base Station	12
•	Cost Per Base Station (CT-2 & CT-2 Plus, 6 RF Channel Capability)	
	- Non SDMA	$2,500
	- SDMA (12 antenna array)	$6,000

* Represents overall market penetration - the model accounts for relative increase in penetration due to PCS subscribers commuting to urban centers during the business day.

Using the above assumptions, SCI's model generated the following totals of serviceable subscribers per PCS base station for SDMA-equipped and Non-SDMA-equipped PCS cell sites.

Number of Subscribers Per Base Station

- CT2/CT2 Plus Non-SDMA 34
- CT2/CT2 Plus/SDMA 459

SCI's model generated the following estimates of total number of PCS base stations required to serve the LACBD.

Number of Base Stations Required

- CT2/CT2 Plus Non-SDMA 15,402
- CT2/CT2 Plus/SDMA 3,850

Based on SCI's estimates of PCS base stations and associated SDMA system costs (assuming use of an SDMA array at each base station capable of supporting six RF channels), the 75% reduction in the number of base stations required translates to a cost savings of $15.4 million if SDMA is used for deployment of PCS in the LACBD. The $15.4 million savings resulting from use of SDMA represents a 40% reduction in overall base station hardware costs for the LACBD.

Total Base Station Hardware Costs

- CT2/CT2 Plus Non-SDMA $38,504,969
- CT2/CT2 Plus/SDMA $23,102,981

Based on the foregoing, SCI submits that it has conclusively demonstrated that deployment of SDMA is not only economically feasible, but will result in substantial cost savings over conventional PCS deployment options and increase the profit potential of PCS operations.

V. IMPLEMENTATION OF PCS WITH SDMA TECHNOLOGY WILL SERVE THE PUBLIC INTEREST

SDMA-based PCS systems will realize a variety of compelling public interest objectives that have concerned the Commission since release of the PCS NOI, and PCS Policy Statement, supra. Chief among these goals are: no interference or disruption to existing microwave users; acceleration of PCS deployment; and increased PCS functionality and feature flexibility. SDMA's ability to realize these public interest objectives is discussed below:

No Interference to Existing Users-- The disruption and inefficiency attending relocation of existing microwave licensees or requiring these users to share assigned frequencies on a co-primary basis with PCS has concerned the Commission since it first considered PCS. As stated in the PCS NOI:

> As public safety entities, broadcasters, common carriers, utilities, and other important entities are using [the 1850-1990 MHz, 1990-2110 MHz, and 2110-2200 MHz] bands at present, we recognize that a reaccommodation of the microwave licensees in these bands could require a considerable amount of time and would likely preclude the implementation of PCN in certain areas for several years.[9]

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[9] 5 FCC Rcd at 3998 (para. 21). This sentiment was echoed in the PCS Policy Statement:

> Important equipment, cost and international considerations suggest that a portion of the spectrum

Initiating PCS with SDMA will resolve these concerns without detriment to incumbent licensees. As previously discussed, dynamic real-time spatial management of spectrum utilization is one of SDMA's most compelling features. This, in turn, eliminates inter-service frequency interference and will allow PCS and incumbent microwave licensees to operate co-channel in the same MSA or other geographical area.

Stated simply, initiating PCS with SDMA eliminates the spectrum allocation dilemma associated with introducing a new personal communications service. Assuming arguendo that SDMA lacked its other well-known attributes-- i.e., spectral efficiency, service quality and design flexibility-- its singular ability to resolve the spectrum allocation dilemma satisfies a paramount public interest objective and should entitle SCI to grant of its instant request.

Accelerated PCS Deployment-- Another persuasive public interest attribute of SDMA derives from the one just discussed. As the Commission noted, relocating incumbent microwave licensees "would likely preclude the implementation of PCN in certain areas for several years." The geographic areas where incumbent

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> to be allocated should come from 1.8 to 2.2 GHz. We recognize that serious issues may exist for incumbents in this band and we intend to reallocate the spectrum needed for PCS with minimum disruption to existing users.

6 FCC Rcd at 6601 (para. 4) (emphasis added).

relocation will prove most difficult and time consuming are likely to be dense urban areas where PCS demand is anticipated to be most intense. Thus, the spectrum allocation problem will delay PCS availability in exactly those areas where it is needed most.

SDMA resolves this concern by allowing PCS and incumbent microwave users to co-exist in the same geographic area. As a result, the delay factor disappears as the daunting challenge acknowledged in the PCS NOI. By accelerating the advent of PCS, SDMA serves a second essential public interest objective.

PCS Functionality and Feature Flexibility-- Reflecting its intrinsic technological attributes, SDMA will allow an increase in functions and features that PCS systems can deliver to end users. By increasing channel capacity without additional (or at reduced) cost, SDMA will encourage PCS operators to provide a more enhanced menu of features and functions to the public. In addition, the SDMA technology will allow certain advanced services (e.g. position determination) to be provided with no significant increase in capital cost.

Increased Flexibility in PCS Licensing-- The spectral efficiencies resulting from SDMA will increase the effective capacity of PCS spectrum allocations. The availability of additional spectrum resource for PCS will allow the Commission to consider adoption of more than one PCS licensing scheme (e.g., two competitive common carrier operators and other private carrier services in the same service area).

VI. PROPOSED PCS LICENSING STRUCTURE AND POLICIES

SCI recommends that the Commission consider and adopt several basic rules to govern PCS licensing. Such rules should promote PCS's rapid introduction and availability, while capitalizing on lessons learned from the Commission's extended experience in regulating cellular communications. PCS's ability to deliver its multifaceted potential of versatile, affordable and convenient personal/mobile communications will surely depend on the underlying regulatory structure that is imposed on this exciting new service.

SCI respectfully submits that any scheme of regulation that promotes PCS's full potential will have the following characteristics:

- o geographic market structure resembling cellular;
- o eligibility restricted to promote competition and innovation;
- o licenses assigned on basis of comparative hearings, at least in 30 to 50 largest markets; and
- o extent of dislocation to existing users and spectral efficiency should be most significant comparative criteria.

These concepts are discussed in sequence below.

<u>Market Structure</u>-- Relying on the MSA/RSA geographic structure developed for cellular communications is advisable on several grounds. Most notably, MSA and RSA boundaries are already in place, and have proven effective in defining initial service areas for cellular operators. Nevertheless, these market definitions,

in conjunction with Commission policy on assignments and transfers, have never inhibited consolidation of cellular systems into multi-market clusters and regional systems.

In addition to adopting cellular's geographical framework, the PCS regulatory framework should also utilize the two carrier per market concept. Spectrally efficient technologies like SDMA will enable the Commission to license two or more PCS carriers in a market; moreover, as already discussed, SDMA's substantial spectrum enhancement will give the Commission multiple options in its conceptual approach to PCS, e.g. licensing two PCS operators in a market as common carriers, and one or two co-market operators as private carriers (or vice-versa).

Promotion of Competition and Ownership Diversity-- The prospect of multiple licensees in individual MSA or RSA markets implies that PCS will be intensively competitive. Nascent rivalry among intramarket PCS carriers will be reinforced by the simultaneous availability in many areas of cellular and SMR, which are all generally regarded as close substitutes. As a result, consumers should have easy access to a diverse array of competing services, and their respective functions and features, at prices approaching cost. In terms of economic theory, this appears close to an optimal result.

SCI advises that promotion of materially enhanced competition and ownership diversity within the subject market should be a principal guiding policy in the issuance of PCS licenses.

Comparative Hearings-- The Commission recently indicated that comparative hearings may be the best method of selecting among mutually exclusive applicants, even for authorizations in the private land mobile service.[5] The Commission acknowledged that comparative hearings were "more exacting" than random selection and that unique characteristics of a particular service may make comparative procedures appropriate. Finally, the Commission noted that, notwithstanding adoption of measures specifically intended to prevent such a result, licensing of the 220-222 MHz band had been perceived as a "treasure hunt" by speculative applicants.

SCI submits that considering these factors in relation to PCS militates in favor of comparative hearings-- at least in the thirty to fifty largest MSAs where PCS demand is anticipated to be most intense and, as a result, where PCS licenses will be most valuable. The close functional connection between cellular and PCS virtually assures that a PCS lottery will attract a multitude of applicants whose principal intention is something other than public service. Accordingly, the Commission should utilize comparative hearings to award PCS authorizations in the largest MSAs.

Comparative Criteria-- Reflecting the foremost regulatory obstacle to PCS's establishment and ultimate development, SCI contends that two criteria should be dispositive in comparing mutually exclusive applicants. The first criterion should be the

[5] Further Notice of Proposed Rulemaking in PR Docket No. 89-552 (Use of the 220-222 MHz Band By the Private Land Mobile Radio Services), FCC 92-27, released January 30, 1992.

extent of interference or disruption to existing licensees in the proposed frequency band(s) allocated for PCS. Applicants will be required to demonstrate quantitatively the extent to which existing users will experience interference or other service degradation by their proposed systems. Applicants proposing a technology (e.g. SDMA) that eliminates or substantially reduces this interference will be preferred because the technology will facilitate rapid availability of service.

The second criterion will be spectral efficiency. Increased efficiency implies lower capital and operating costs, making PCS a more affordable service other things being equal. At the same time, a spectrally efficient proposal increases the Commission's regulatory flexibility and creates spectrum for additional PCS allocations or other needed services. Accordingly, spectral efficiency should be the second comparative criterion.

VII. OTHER MATTERS RELATING TO SCI'S INSTANT REQUEST

As discussed fully in this Section, SCI's instant request is in full compliance with all Commission Rules. In fact, SCI submits that its foregoing demonstration of qualifications far exceeds the Commission's threshold showing requirement for grant of a Pioneer's Preference. For this reason, SCI should be awarded PCS licensing preferences in each of the three MSA markets where plans experimental tests and demonstrations.

A. SCI's Request Complies With All Commission Rules and Policies

The content requirements for a Pioneer's Preference Request, as set forth in Section 1.402 of the Commission's Rules are met or exceeded herein. In accordance with Commission Rules, the instant request demonstrates that implementing SCI's PCS SDMA technology is technically feasible.[9] In addition, SCI is unaware of any conflicts with existing Commission Rules that will result if the instant request for a PCS Pioneer's Preference is granted. For these reasons, SCI has met the Commission's regulatory requirements and is qualified for grant of a Pioneer's Preference.

B. No Petition for Rulemaking Is Required With This Pioneer's Preference Request

The integral relationship between SCI's PCS SDMA technology and the service and technical issues raised in General Docket No. 90-314 negates the need for SCI to accompany this Pioneer's

[9] See Section 1.402(a) of the Commission's Rules. See also, Pioneer's Preference Order, 6 FCC Rcd at 3493, para 39; Pioneer's Preference Reconsideration Order, at paras 10-11. SCI also provides herein a detailed showing of the economic feasibility and attendant cost benefits that will accrue from its PCS SDMA technology. In support of this request, SCI reserves the right to submit, prior to release of a Notice of Proposed Rulemaking in General Docket No. 90-314, additional technical and economic data from SCI's PCS SDMA testing that are derived by SCI subsequent to the instant request's filing.

Preference request with a petition for rulemaking.[7] In General Docket No. 90-314, the Commission sought proposals for selecting PCS spectrum access techniques and appropriate technology applications to support use of these techniques by PCS systems.[8] The Commission also solicited proposals on methods for mitigating the impact on existing users that might result from establishing a primary PCS allocation.[9] SDMA's spectral efficiency and interservice compatibility enhancements respond directly and convincingly to these key issues in General Docket 90-314. Therefore, SCI need not file a petition for rulemaking here.

C. Area for Which Preference is Requested

Because of the sheer magnitude of the enhancements that SCI's SDMA technology will have on the implementation of PCS in the United States, SCI submits that it should be awarded a preference in the PCS licensing process for each of the MSA's where SCI's SDMA tests and demonstrations are planned. Accordingly, SCI provisionally requests that upon grant of SCI's Pioneer's

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[7] See Section 1.402(a) of the Commission's Rules. See also, Pioneer's Preference Reconsideration Order, FCC 92-57, at 8, para 19.

[8] See e.g., Notice of Inquiry in Gen Docket No. 90-314, 5 FCC Rcd 3995, 3999, para 29 (1990) ("PCS NOI"). See also, Policy Statement in Gen Docket No. 90-314, 6 FCC Rcd 6601, para 8 (1991) ("PCS Policy Statement"), at para 8.

[9] See PCS NOI, 5 FCC Rcd at 3997, para 19; PCS Policy Statement, 6 FCC Rcd 6601, at para 8.

Preference request, the Commission authorize SCI to construct and operate PCS systems serving the Los Angeles, California MSA, the Long Beach, California MSA, and the Seattle, Washington MSA. If the Commission determines that it is not possible to award SCI PCS licenses in each of the three designated MSAs, SCI hereby selects the Los Angeles MSA as an alternative choice. In the event the Commission does not adopt MSAs as a PCS service area definition, SCI reserves the right to designate an alternate service area(s) where its Pioneer's Preference shall apply.

VIII. CONCLUSION

SCI's pioneering role in the development and verification of proprietary PCS SDMA technology, in combination with the pivotal efforts of SCI, and its predecessors in interest, in the development of other key PCS technical and administrative components, renders SCI a prime candidate for award of a Pioneer's Preference in the Commission's PCS licensing proceeding. For the foregoing reasons, SCI respectfully submits that the Commission award SCI a Pioneer's Preference in the PCS licensing proceedings in General Docket No. 90-314. SCI provisionally requests that upon grant of SCI's Pioneer's Preference request, the Commission authorize SCI to construct and operate PCS systems serving the Los Angeles, California MSA, the Long Beach, California MSA, and the Seattle, Washington MSA. If the Commission determines that it is not possible to award SCI PCS licenses in each of the three designated MSAs, SCI hereby selects the Los Angeles MSA as an alternative choice. In the event the Commission does not adopt MSAs as a PCS service area definition, SCI reserves the right to designate an alternate service area(s) where its Pioneer's Preference shall apply.

Respectfully submitted,

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APPENDIX A

Appendix to Request of *Spatial Communications, Inc.* for a Pioneer's Preference in the Licensing Process for PERSONAL COMMUNICATION SERVICES

Implementing SDMA in the PCS Environment
Technical and Economic Factors

4 May 1992

Spatial Communications, Inc.

Appendix to Request of *Spatial Communications, Inc.*

for a

Pioneer's Preference in the Licensing Process

for

PERSONAL COMMUNICATION SERVICES

Spatial Communications, Inc.

4 May 1992

CONTENTS

1. Introduction

This document describes the application of a new technology to improving spectral efficiency and signal quality in Personal Communication Systems (PCSs). The technology employs *smart antennas* to separate signals not only based on their frequency content, but their spatial location as well. This Spatial Division Multiple Access (SDMA) technology is compatible with currently employed analog and digital signal modulation schemes including Frequency-Division Multiple Access (FDMA), Time-Division Multiple Access (TDMA), and Code-Division Multiple Access (CDMA), and can be used to increase the spectral efficiency (number of communication channels) and signal quality in all PCSs employing such schemes *without increasing the amount of allocated frequency spectrum.*

Many of the problems inherent in multi-user cellular-type wireless communication systems are a consequence of the omnidirectional nature of transmission of RF signals. While wide-area (omnidirectional) transmission is essential in current systems since the relative locations of the receivers and transmitters are not known, it *pollutes* the electromagnetic environment by radiating most of the total transmitted power in directions other than *toward* the intended receiver. This leads directly to (cochannel) interference problems which severely limit the overall system capacity and quality.

The fundamental concept involved in SDMA is exploitation of the spatial dimension in a heretofore unthought of manner in wireless (mobile) communication networks. By using more than one receiving antenna, *i.e.*, an array of simple antennas, and *spatially* sampling the electromagnetic fields, it is possible to estimate the directions-of-arrival (DOAs) of multiple cochannel signals and to *separate* the underlying source waveforms. By using multiple transmit antennas, energy can then be selectively directed toward the intended receivers without interfering with other users and keeping RF pollution to a minimum. Since multiple users are allowed to occupy the same (frequency or code) channel at the same time, spectral efficiency is greatly enhanced, and by spatially selectively transmitting RF energy, RF pollution and hence interference is greatly reduced. This also increases spectral efficiency by increasing the capacity of each communication link, a consequence of reducing the overall system noise/interference level. Furthermore, SDMA's multiple receive antennas provide gain at the output of the SDMA processor, gain which can be used to reduce the power of the transmitters at the other end of the link, thus increasing the talk-time of portable mobile units. Though similar in structure to phased-arrays, the signal processing performed in the SDMA system is state-of-the-art technology, the real-time implementation of which has only recently been made feasible with the advent of high-speed special purpose digital signal processing hardware.